AMENDMENTS TO THE SPECIFICATION

The following numbered paragraphs of the specification are amended to read as follows:

[0015] Disclosed herein in an exemplary embodiment is a method and system reducing torque ripple and audible noise. In an exemplary embodiment, the motor back electromotive force (BEMF) characteristic is sampled and processed to formulate an envelope to modulate the motor drive waveforms to facilitate optimal commutation. The method and system involves synthesizing a drive waveform envelope for the motor BEMF each time the motor starts and employing the synthesized waveform to compensate motor voltage commands for variations including, but not limited to, thermal variation, magnet aging, and even cracked magnets. In an exemplary embodiment, during the start up of the motor, it is stepped in open loop mode for a selected amount of electrical degrees. Meanwhile, the period of the back-EMF waveform and ~~it's~~its magnitude are sampled. It should be appreciated by one skilled in the art that the sampling will depend on the motor construction and characteristic and should be performed to ensure that sufficient resolution is provided to capture and synthesize the waveform.

[0017] It should be noted that the exemplary embodiments as disclosed herein provide for a reduction in torque ripple and audible noise over existing designs. This is desirable in all applications, and may actually be critical in some application such as medical instrumentation and disk storage systems. In particular, low torque ripple and minimal audible noise are beneficial characteristics of motors of choice used in ~~for~~ applications such as high power blowers and fans associated with cooling critical components, ~~most particularly associated with~~such as computers. Moreover, it will readily be appreciated that while the exemplary embodiments described herein are made with reference to a brushless DC motor, the invention is readily applicable with

appropriate variation to other motor and motor controller types including, but not limited to, DC, AC, ~~Brush~~brush, and ~~Brushless~~brushless.

[0017] Referring initially to Figure 1, there is shown a schematic diagram of ~~an existing~~a control circuit 10 for a sensorless brushless DC motor 12, suitable for use in accordance with an embodiment of the invention. As is well known in the art, an inverter 14 is used to electronically commutate the phase currents supplied by a DC bus 16 to the motor 12. For a motor having three phase windings, a conventional inverter 14 includes six individually controlled switching devices, designated in Figure 1 as Q1 through Q6. The switching devices Q1 through Q6 may be transistors, junction transistors, Field Effect transistors (FETs), Metal Oxide Field Effect transistors (MOSFETs), Insulated Gate Bipolar Transistors (IGBTs), Silicon Controlled Rectifiers (SCR), and Triacs solid state relays and the like, as well as combinations including at least one of the foregoing. In the example shown, the switching devices are (MOSFETS); however, other types of solid state switching devices may also be used as discussed above.

[0023] Referring now to Figures 2 and 3, it will be appreciated by those skilled in the art that most BLDC motors exhibit a BEMF profile that is somewhat trapezoidal and therefore may be approximated as trapezoidal. Figure 2 depicts an ideal BEMF waveform. However, with actual magnets exhibiting actual field gradients, the waveshape of the profile for the BEMF is not purely trapezoidal. In addition, when configured in a control circuit 10 as employed in Figure 1, the wave shape of the BEMF as measured by the circuit 10 via the attenuated phase voltage signals 24 is further reconfigured. Figure 3 depicts an example of the BEMF waveform including this modification. It is noteworthy to appreciate that the bottom of each waveform as depicted in the figure is substantially flat. This flattening is due to freewheeling diodes on the inverter 14, as the floating phases of the motor 12 get clamped to the ground rail, which is increasing as the bulk caps discharge~~,~~. ~~in~~ In the actual drive, this would be clamped to -

350V. It will readily be appreciated that the real BEMF of the motor alone does not exhibit this clamping. Figures 4a and 4b depict measured BEMF waveforms for two existing motors for illustration. The figures depict the voltage seen by the drive inverter 14 as the motor 12 rotates freely with no phase drive. These plots were taken just as the motor drive was turned off.

[0026] This approach provides a methodology for synthesizing individual full period wave shapes for each motor phase that may be employed for the modulation and control of the voltage commands to the motor 12. Advantageously, an exemplary embodiment of the invention facilitates the waveform capture/synthesis by taking advantage of the symmetry of the motor 12, and therefore the BEMF waveforms, by capturing less than all of the phase voltage signals 24 and utilizing the captured information to synthesize the waveforms for other non-captured phases. ~~.~~It will also be appreciated that by considering the symmetry of the motor 12, the BEMF wave forms may be synthesized capturing as little as one half of the positive period for a single phase, and/~~of~~ or capturing the full waveform for each of the three phases. Advantageously, the first approach utilizes the least memory and exhibits the shortest sampling duration but is computationally the most extensive, while the latter approach requires significant storage and a longer duration, but utilizes minimal computation. It will also be appreciated that other approaches between these "extremes" are possible and considered. For example, in an exemplary embodiment, the positive portion for two phase voltage signals 24 are sampled and measured. This tradeoff ~~providing~~ provides a compromise between sampling duration, memory allocation, and computational intensity.

[0027] Therefore, once again with reference to Figure 5, in an exemplary embodiment, the BEMF waveforms may be synthesized with a reconstruction filter 30 employing the following relationship that considers the multiphase characteristics of the motor 12 and its construction symmetry. For example, it will be appreciated that the waveforms may be synthesized by: (1) ~~C~~capturing and measuring the positive portion of

the phase voltage signal 24 for phase A; (2)~~.~~ ~~Capturing~~ capturing and measuring the positive portion of the phase voltage signal 24 for phase B~~.~~; (3) ~~N~~negating the phase B positive portion and shifting the resultant in time, advanced 60 electrical degrees to complete that magnets profile for the phase A signal. In other words, for ~~phase A, for~~ the interval of 0-180 degrees for phase A, the waveform is defined by the phase A voltage signal; for the interval of 180 -360 degrees, the BEMF waveform for phase A is defined as the negative of the positive portion of the phase B waveform shifted 60 electrical degrees and concatenated with the 0 – 180 degree portion. The profile for the phase A waveform may readily be stored in memory 32. This completes the profile for phase A, as the magnet ~~1,~~ has now passed to the next phase pair, which is wired at the opposite polarity. Adjacent legs of the stator are wired out of phase.

[0030] In yet another exemplary embodiment, an optional equalizer/normalizer 34 may be employed on the sampled BEMF waveform data after it is reconstructed by the algorithm presented above to compensate for this variation as a function of the motor speed. The equalizer/normalizer may be as simple as magnitude compensation and normalization, or as complex as an adaptive equalizer with compensation for adjacent phase noise. If a more complex equalization were desired, this could be done spectrally (in the frequency domain, with greater accuracy, a finite impulse response (FIR) or infinite impulse response (IIR) method). In one exemplary embodiment, a finite impulse response (FIR) or infinite impulse response (IIR) equalizer is employed to address magnitude and spectral compensation. Advantageously, since the processing described herein for the exemplary embodiments is only completed once for the entire dataset, e.g., upon each startup, executing an equalizer function is not that significant a load on the CPU. Once again, following equalization/normalization, the normalized BEMF waveforms may be saved and stored in memory ~~50~~32.

[0031] The following illustration depicts an application of the exemplary embodiments. The motor start sequence includes a series of open loop commutation

pulses~~,~~ to start the motor 12 is spinning at some low speed. At this time, the all three phases are sampled, capturing the phase voltage signals 24 and a waveform profile is stored in memory ~~34~~32. It will be appreciated that this captured waveform data is "one-sided" as the motor drive (inverter 14) clamps the phase~~s~~ voltage signals 24 to the ground rail as described earlier. The above_mentioned algorithm and methodology may then be employed to perform the reconstruction and establish an array or table with each of the values associated with the reconstructed BEMF waveforms. The reconstruction filter 30 employs the trigonometric and linear transforms described above to extract and synthesize the magnetic profile for all three phases.

[0033] Continuing with Figure ~~6~~5, central to creating a signal of varying frequency and amplitude to drive the motor 12 is the correlator/scaler 36. The BEMF waveforms stored in memory 32 include an image of the waveform at one frequency only (corresponding to an initial selected motor speed), and at the maximal amplitude. The correlator/scaler 36 is employed to employ the existing commutation state, (associated with existing speed control) as reference, and map the stored BEMF waveform period to a length corresponding the existing speed of the motor 12. The scale associated with the mapping may readily determined by the speed estimator 38 based on the current motor speed relative to the initial motor speed at which the BEMF waveforms were sampled. Said another way, the period of the synthesized phase waveform for each phase is scaled in time to equal the period of the PWM for a given commutation state. In an exemplary embodiment, the scaling is accomplished with a correlator or piecewise linear/polynomial interpolation algorithm.

[0034] It will be appreciated~~,~~ ~~that~~ at this point that the PWM waveform of the shape of the motor back-EMF is represented~~,~~ at the appropriate frequency for the current motor speed, but also at maximum amplitude. _The final process is to therefore scale the magnitude based upon the current motor speed (since the BEMF waveform were previously magnitude normalized) at modulator 40. The modulator ~~received~~ receives the

correlated and frequency scaled BEMF waveform, which is then employed to modulate the existing speed control. The speed regulator, shown generally as 42, computes this scaling factor proportional to the speed error signal. The speed control employed may be of various configurations including, but not limited to: proportional, proportional-integral (PI), proportional-derivative (PD), proportional-integral-derivative (PID), and the like. Figure 6 is a diagram illustrating a waveshape for the BEMF of a motor exhibiting the effects of a reduction of motor speed.

[0035] It will be appreciated that each element of the equalized, time-scaled BEMF waveform is amplitude scaled in real time. Advantageously, this means ~~is~~ that as the motor 12 ~~changed~~ changes speed during commutation sub-intervals, the corrections to the BEMF waveforms are scaled as well. In addition, it will be appreciated that the approach employed provides a significant memory savings, as one "master" copy of the three BEMF phase waveforms, and one small buffer for each commutation sub-interval per active phase need be stored. This real-time scaling is preferred as it is most flexible and memory efficient, however, scaling the waveforms in advance could also be utilized.

[0036] The system and methodology described in the numerous embodiments hereinbefore provides a robust means to reduce torque ripple and audible noise. In addition, the disclosed invention may be embodied in the form of computer-implemented processes and apparatuses for practicing those processes. The present invention can also be embodied in the form of computer program code containing instructions embodied in tangible media ~~16~~17, such as floppy diskettes, CD-ROMs, hard drives, or any other computer-readable storage medium, wherein, when the computer program code is loaded into and executed by a computer 20, the computer 20 becomes an apparatus for practicing the invention. The present invention can also be embodied in the form of computer program code, for example, whether stored in a storage medium, loaded into and/or executed by a computer, or as data signal 15 transmitted whether a

modulated carrier wave or not, over some transmission medium, such as over electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the computer program code is loaded into and executed by a computer, the computer becomes an apparatus for practicing the invention. When implemented on a general-purpose microprocessor, the computer program code segments configure the microprocessor to create specific logic circuits.